Reverberation Modeling Workshops

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LONG-TERM GOALS

Reverberation modeling is a fundamental component in numerous Navy applications including sensor performance predictions, mission planning, wargaming/campaign analysis, and most recently, synthetic sonar operator training. Because of increased interest in littoral operations, requirements for accurate system performance predictions are placing increasing demands on predictions of reverberation. Requirements for better reverberation modeling are coming from both legacy systems that employ new tactics and from new distributed autonomous systems that need deployment and control strategies. Interest in synthetic training has grown due to the increased costs of at-sea training that have resulted from limited platform availability and from restrictions imposed by marine mammal mitigation. Demands on reverberation prediction include better physics and statistical characterizations; these are required by the need to simulate bistatic and multistatic scenarios in complex (range-dependent) and variable environments using sophisticated wideband signals. Theoretical advances, the availability of high performance computers, and rapidly expanding communication bandwidths have made it technically feasible to implement many of the modeling changes necessary to meet these new requirements. The resulting recent progress in basic and applied research provides an opportunity to review current capabilities and propose improvements. These improvements, combined with operational Navy requirements, will help define new Navy Standard Models or changes to existing Navy Standard Models. Further substantiating a need, a recent report[1] concerning verification and validation (V&V) of geoacoustic inversion techniques noted the lack of a proven method to generate synthetic reverberation data designed to test inverse techniques on reverberation data.

Although there are currently numerous research reverberation models, there has been very little verification and validation – nothing comparable to what has been accomplished by way of benchmarking for forward propagation modeling.[2] The long term goals of this project are (1) the creation of a series of well-defined problems designed to illuminate the capabilities and limitations of various approaches to reverberation modeling and (2) the development of "consensus" solutions to

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[1] D. King, D. Knobles, J. Perkins, M. Siderius, "Recommendations for the Geoacoustic Inversion Toolkit," NRL Memorandum Report NRL/MR/7140--06-8938 (2006).

[2] See "Solutions to Range-Dependent Underwater Acoustics Benchmark Problems," J. Acoust. Soc. Am. **87,** 1497-1547 (1990).

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14. ABSTRACT
Reverberation modeling is a fundamental component in numerous Navy applications including sensor performance predictions, mission planning, wargaming/campaign analysis, and most recently, synthetic sonar operator training. Because of increased interest in littoral operations, requirements for accurate system performance predictions are placing increasing demands on predictions of reverberation. Requirements for better reverberation modeling are coming from both legacy systems that employ new tactics and from new distributed autonomous systems that need deployment and control strategies. Interest in synthetic training has grown due to the increased costs of at-sea training that have resulted from limited platform availability and from restrictions imposed by marine mammal mitigation. Demands on reverberation prediction include better physics and statistical characterizations; these are required by the need to simulate bistatic and multistatic scenarios in complex (range-dependent) and variable environments using sophisticated wideband signals. Theoretical advances, the availability of high performance computers, and rapidly expanding communication bandwidths have made it technically feasible to implement many of the modeling changes necessary to meet these new requirements. The resulting recent progress in basic and applied research provides an opportunity to review current capabilities and propose improvements. These improvements, combined with operational Navy requirements, will help define new Navy Standard Models or changes to existing Navy Standard Models. Further substantiating a need, a recent report1 concerning verification and validation (V&V) of geoacoustic inversion techniques noted the lack of a proven method to generate synthetic reverberation data designed to test inverse techniques on reverberation data

15. SUBJECT TERMS

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these problems, which cannot be solved directly in closed form, that can serve as benchmarks for new models or model upgrades.

OBJECTIVES

As discussed above, the goals of this project are (1) the creation of a series of well-defined problems designed to illuminate the capabilities and limitations of various approaches to reverberation modeling and (2) the development of "consensus" solutions to these problems, which cannot be solved directly in closed form, to serve as benchmarks for new models or model upgrades. In the process of accomplishing and documenting these goals, we will also provide a summary of each of the participating models. This includes inputs, outputs, theoretical basis, assumptions/limitations, and computational speed. This information will be supplied by participants and compiled by the organizers. Some information will be available on the speed/accuracy trade-offs available in these models.

APPROACH

The general approach to accomplishing these goals is via a series of Reverberation Modeling Workshops. To date, two Reverberation Modeling Workshops have been conducted under joint sponsorship from ONR and PEO C4I (PMW 120). The first workshop was held at the Pickle Research Center in Austin, Texas, in November 2006, and the second workshop was held at the same site in May 2008. Dr. David Knobles (ARL/UT) served as the local host and point-of-contact. To provide focus to these workshops, modelers were asked to bring their solutions to a set of pre-defined problems. The problems of interest were mainly in shallow water environments, and restricted to a frequency range < 10 kHz.

Although the two workshops were conducted prior to the current year, the co-chairmen of the workshops, Mr. John Perkins (NRL) and Dr. Eric Thorsos (APL/UW), have continued to refine the workshop problems and iterate with the participants to bring the solutions into agreement.

This was not a competition between models, especially since ground truth solutions are not available. The organizers collected the solutions and plotted them for comparison purposes. By iterating with participants, the goal was to have all solutions agree, or to understand why a particular solution may not agree with the consensus. The problems were designed so that the mutual agreement (or non-agreement) of solutions would provide insight about the strengths/weaknesses of the various models.

WORK COMPLETED

The co-chairmen of the workshops conducted in 2006 and 2008 have continued to refine the workshop problems and have repeatedly collaborated with the participants to bring the solutions into agreement. At this point the agreement among the participating models is quite good for a total of nine of the original twenty problems from the first workshop. These twenty problems were defined by a Problem Definition Committee chaired by Dr. Kevin LePage. The workshop problems (and other relevant information) are available at the anonymous ftp web site listed at the top of this document. The RESULTS section below shows examples of the agreement between models.

All of the nine problems for which there are consensus solutions are for reverberation problems with relatively simple environments. The consensus solutions are for a rough ocean bottom, a rough ocean surface, and a rough ocean bottom described by Lambert's Law roughness. For each of these three scattering environments, we have solutions corresponding to isovelocity, summer and winter sound speed profiles. (Each 'solution' also covers three frequency bands centered at 250 Hz, 1000 Hz and 3500 Hz.)

For the second workshop, an additional ten problems were defined; five were extensions to some problems from the first workshop, and five were totally new "Data Inspired Problems" (See the paragraph below). The five modified problems included (1) the addition of a target sphere, (2) the addition of near surface bubbles, (3) the addition of fish schools, (4) the addition of a heterogeneous sediment (mud) layer, and (5) the addition of bottom clutter. (Note that the last two have not yet been posted to the web site.)

One aim of the second workshop was to expand the problem set to include reverberation phenomena observed in data sets of Navy interest. Since the goal is to establish consensus solutions to well-defined problems (rather than explaining a particular data set), the concept of a "Data Inspired Problem" was developed. In these problems, all relevant, but unknown, environmental parameters corresponding to a measured reverberation data set are given reasonable values; in doing so, the problem becomes completely defined yet retains the features of interest in the original data. The five data inspired problems included (1) mud volcanoes, (2) seamounts, (3) acoustic focusing, (4) multistatics, and (5) a bottom bounce environment. These problems were designed by a Data Definition Committee chaired by Dr. Roger Gauss.

Even defining these problems was not straightforward. A crucial consideration was to design the problems so that equivalent loss and scattering strength vs. angle and frequency could be provided to those models that cannot treat the exact scattering problem as defined. This is because many models do not have much flexibility in the scattering kernels they employ.

While it is a significant accomplishment to have defined the various problems and to have established consensus solutions to some, many of the problems remain unsolved; therefore a possible third workshop has been discussed. The current need is for more sponsors of reverberation modeling to require the model developers to rely on these benchmark problems as part of a verification and validation process.

As a consequence of the first workshop, a special session on reverberation modeling was held at the November/December 2007 meeting of the Acoustical Society of America in New Orleans.

Workshop co-chairman Dr. Eric Thorsos presented an invited paper on the reverberation modeling workshops at the International Symposium on Underwater Reverberation and Clutter (ISURC), Lerici, Italy, September 9-12, 2008. This paper appears in the published proceedings.

This year, the workshop co-chairmen have organized a special session on reverberation at the Acoustical Society of America to be held in San Antonio in October 2009.

RESULTS

The main deliverable for this project will be a technical report/proceedings detailing the characteristics of each of the participating models and a comparison of the solutions received. The workshop co-chairmen, working directly with individual modelers, have identified and resolved numerous minor issues preventing close agreement between solutions. Most of these issues concern normalizations and the consistent treatment of scattering. However, more serious scientific issues were also raised; probably the most important issue identified is the treatment of reflection loss for the total field.

The reflection loss issue concerns the (widespread) use of the plane-wave Rayleigh reflection coefficient (for the ocean bottom) and the Modified Eckart loss (for the ocean surface) each time a ray (or mode) interacts with a boundary. In the plot below, we see two families of results with differences of ~15 dB at 10 seconds. The "upper" family of curves employs the Rayleigh reflection coefficient and the "lower" set use the supplied coherent loss table corresponding to the given roughness. At first, one might say the latter are "correct," but the true solution at longer ranges requires multiple boundary interactions so that the long-range behavior might actually be better approximated using the Rayleigh reflection coefficient; independent simulations of forward propagation suggest this may be correct. This issue was raised prior to the workshop and led problem solvers to use each approach. The "true" answer lies somewhere in the middle of the two groups, most likely closer to the upper curves for which the Rayleigh reflection coefficient was used. However, for scenarios with rougher boundaries (as with the ocean surface at a high sea state) the true answer may lie closer to the lower family.

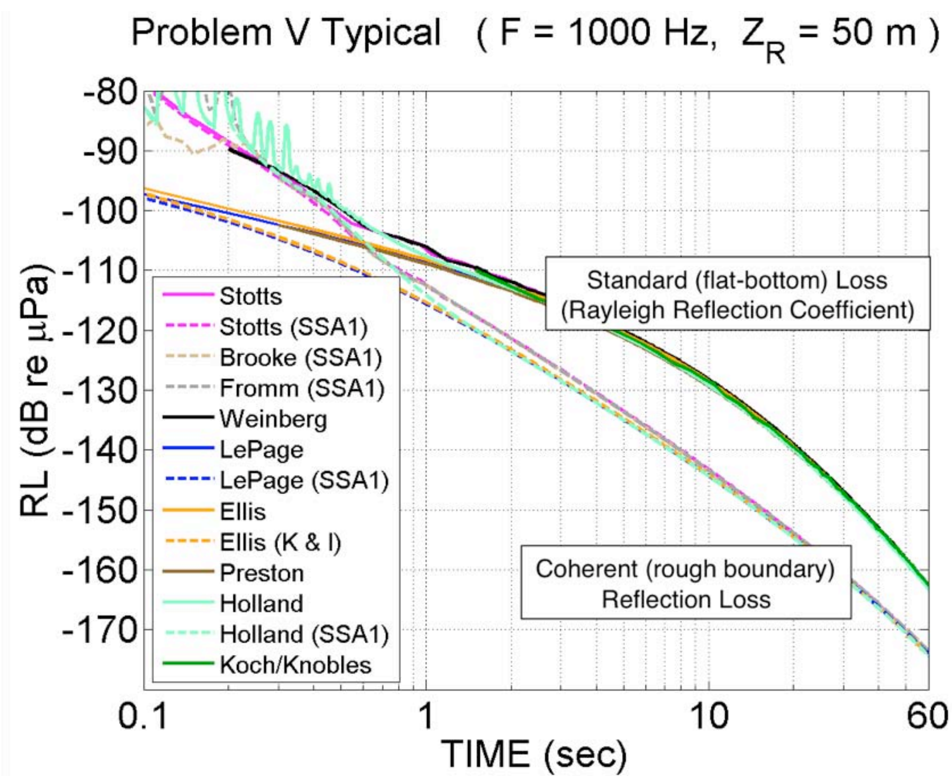

Figure 1: Reverberation levels versus time for workshop problem number five (1000 Hz). The plot shows two families of curves, each corresponding to a different treatment of the reflection loss at the bottom boundary. At ten seconds, these families differ by approximately 15 dB.

\Figure 2 shows an example where we achieved close agreement is achieved between sixteen independent solutions. These are solutions to a 3D Lambert's law problem and the close agreement at longer times from so many solutions is rewarding. This degree of agreement was accomplished, at least in part, by the post-workshop collaborations that took place.

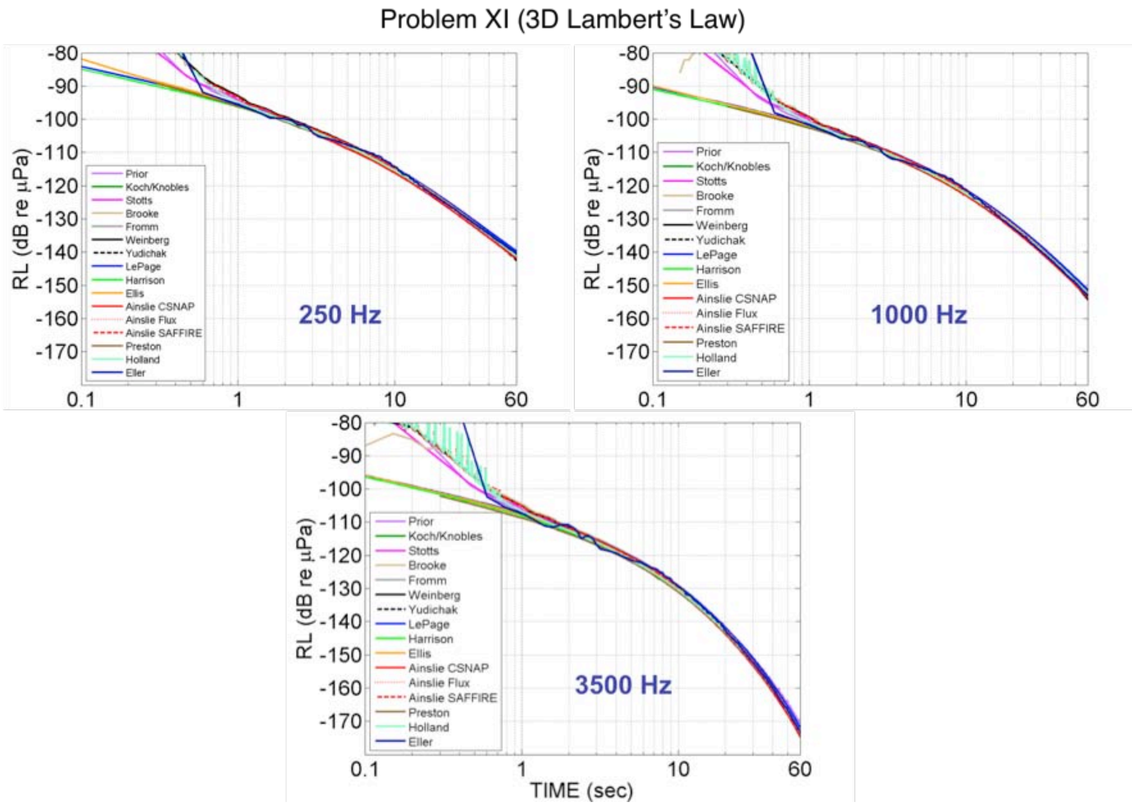

Figure 2: Reverberation levels versus time for workshop problem number eleven. The plots show sixteen independent solutions to a 3D Lambert's Law problem for three frequency bands. The curves are tightly bunched, lying within a range of three to four dB at ten seconds, indicating a consensus solution to this problem.

IMPACT/APPLICATIONS

Please see the discussion under in the **LONG-TERM GOALS** section above.

TRANSITIONS

The reverberation modeling workshops are being co-sponsored by PEO C4I (PMW-120). Recommendations will be made to PMW-120 for new models or modifications to existing models. Inverse algorithms that determine geoacoustic parameters from observed reverberation are also potential transitions to PWM-120. Additionally, the ONR FNC on High-Fidelity Active Sonar Training (HiFAST) will be looking at reverberation modeling improvements (accuracy and speed) as a technological improvement for various sonar trainers.

RELATED PROJECTS

There are numerous projects addressing issues in reverberation modeling. This is reflected in the variety of research organizations participating in the workshops: Applied Research Laboratory, Pennsylvania State University, Applied Research Laboratories, University of Texas, Applied Physics Laboratory, University of Washington, Naval Research Laboratory, Defence Research and Development Canada, NATO Undersea Research Centre, Applied Physics Laboratory, Johns Hopkins University, Northeastern University, Science Applications International Corporation and others.

REFERENCES

1. John S. Perkins and Eric I. Thorsos, "Overview of the Reverberation Modeling Workshops," J. Acoust. Soc. Am. **122**, 3074 (2007).

2. Eric I. Thorsos and John S. Perkins, "Reverberation Modeling Issues Highlighted by the First Reverberation Modeling Workshop," J. Acoust. Soc. Am. **122**, 3091 (2007).

3. E. I. Thorsos and J. S. Perkins, "Overview of the reverberation modeling workshops," in proceedings of the International Symposium on Underwater Reverberation and Clutter, ed. by P.L. Nielsen, C.H. Harrison and J.-C. Le Gac, 9-12 September 2008, Lerici, Italy (NURC, La Spezia, Italy, 2008), pp. 3-14.

4. D. King, D. Knobles, J. Perkins, M. Siderius, "Recommendations for the Geoacoustic Inversion Toolkit", NRL Memorandum Report NRL/MR/7140--06-8938 (2006).

5. John S. Perkins and Eric I. Thorsos, "Update on the reverberation modeling workshops," J. Acoust. Soc. Am. **126**, 2208 (2009).

Also see the documents at the anonymous ftp web site
ftp://ftp.ccs.nrl.navy.mil/pub/ram/RevModWkshp_II